# A Real-time Offshore Borehole Observation Network in Japan

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*Described are methods for transmitting back to shore in real-time, data from seismic sensors placed in boreholes. While primarily a means for providing scientific data to further the understanding of the area's seismology, it is also possible that data from these boreholes, if transmitted continuously and reliably to shore, might also be incorporated into a network designed to provide early detection and warning of earthquakes and tsunamis. While some sensor packages have been linked to shore using submarine cables, this paper explores the use of a buoy-based system called Ocean Net. With this system, data is carried from seafloor to a surface buoy via a fiber optic cable, whereupon it is transmitted on to shore via a high bandwidth (2-Mbps) satellite link.*

## 1. DISASTROUS EARTHQUAKES AND EARTHQUAKE OBSERVATION IN JAPAN

Most of the disastrous earthquakes affecting Japan have originated off the coast (Fig.1). Moreover, some of these earthquakes have also resulted in tsunamis [1].

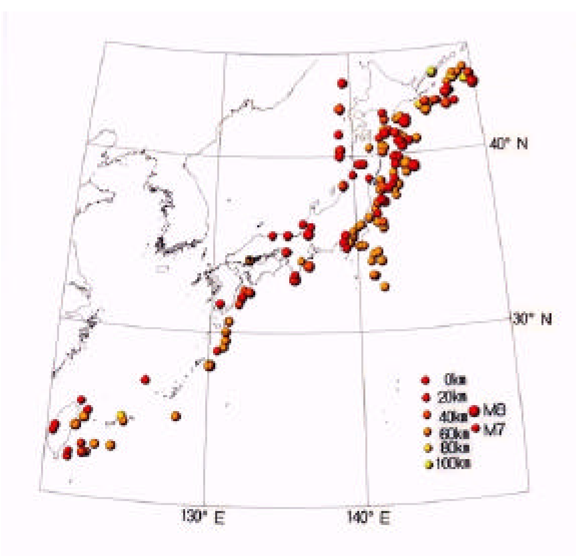


Fig. 1. Earthquakes of M7 or Greater (1885-1996) at Depth of 100km or Less

With the aim of understanding and reducing the destruction of earthquakes, considerable effort and attention has been focused upon monitoring and measuring the seismic activity and crustal movement in this region, particularly from onshore sites. Figure 2 shows one example of a high sensitivity seismograph network as it appeared in March 1997. According to the Headquarters for Earthquake Research Promotion (ERP), Prime Minister's Office, by the end of March 2001, this onshore network comprised about 1,100 installations of high sensitivity seismographs set at horizontal intervals of 20-km.

Fig.2. High Sensitivity Seismograph Network as of March 1997

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Regarding offshore installations, the cited 1997 ERP Headquarters reference [2] observed, "…it is desirable to lay cables over the hypothetical focal regions (to the region near the trench axis in the Pacific Ocean), and to distribute seismometers in a plane aiming at horizontal intervals of 20-km. Furthermore, it is desirable to construct an observation system with broadband and wide dynamic range as well as inland seismic observation. Regarding the cable-type ocean-bottom seismometers, from the viewpoint of effective promotion, the Headquarters believes that it is appropriate to select the region and to try to install them."

Having said this, it has been determined that, as of today, there still remains far fewer offshore observatories than are necessary [3] to adequately monitor and perhaps even serve as an early detection system for the disastrous earthquakes endemic to the region. At present there are actually fewer than ten such systems [4] off the coast of Japan as compared to thousands of sensors onshore. The number of onshore permanent sensors to measure seismic activity and crustal movement is now summed up over 5,000, and the ERP Headquarters is planing to accelerate the construction of offshore installations including sensors for tsunami detection.

## 2. OFFSHORE EARTHQUAKE OBERVATION

As a result of their sensitivity, Ocean Bottom Seismometers (OBS) designed to be laid upon the seafloor can suffer from noise caused by structure-induced turbulence from minimal nearby water motion, pressure fluctuations caused by long ocean waves, or even changes in temperature. One solution to mitigate this anomalous noise and to ensure good coupling is to set the sensors in a drilled borehole. Such an installation can facilitate observation of crustal deformation by also installing a strain meter and tiltmeter inside the borehole near a seismogenic zone.

Since the 1950s, the oil industry has drilled more than 160 offshore wells off the coast of Japan. The first offshore drilling in Japan was conducted in water depths less than 20-m and drilling depths less than 1,000-m. Since this time, exploration drilling has spread out farther offshore, corresponding to greater water depth and/or drilling depth. Recent activity is at water depths in the range of 1,000-m and/or drilling depths of 5,000-m. Figure 3 is a photograph of offshore drilling in Japan by a semi-submersible drilling rig.

Recent scientific drilling conducted in this region by the Ocean Drilling Program (ODP) is worthy of mention. Some deep water (2,000-m class at Leg 186 and 5,000-m class at Leg 191) wells have been completed within which some sensors have been placed. Figure 4 depicts a Borehole Instrument Package that was installed during ODP Leg 186 on the landward side of the Japan Trench, directly above the seismogenic zone of the subduction plate boundary.

Fig. 3. Offshore drilling in Japan

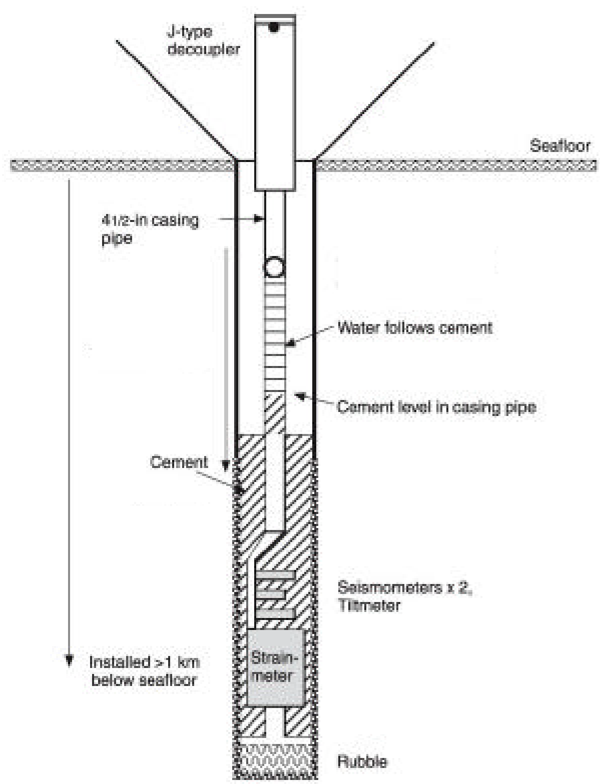


Fig. 4. Schematic of Borehole Sensors
(Courtesy of Dr. Suyehiro of JAMSTEC)

While the placement of some sensors in these boreholes has been successfully accomplished, as water depths and/or drilling depths increase, some advances in methods and equipment may benefit the practice. Particular emphasis must be devoted to reducing the costs of these operations and installations. Among the possibilities under evaluation to potentially reduce the costs of these operations will be “slim hole drilling technology” including coiled tubing drilling.

## 3. REAL-TIME DATA TELEMETRY

Major earthquakes in densely populated urban areas are likely to cause extensive damage and disruption to society. In order to provide vital information to help minimize the immediate impact in such areas, it is not only necessary to install a network of sensitive instrumentation, but also to provide a reliable method for providing this information back to controls on shore in real-time or as near real-time as possible [5].

For example, a real-time measurement and reporting system installed around the Tokyo area, could potentially detect a strong shake originating at the hypothetical focal region (near the trench axis in the Pacific Ocean) and provide warning to densely populated urban areas in time to permit at least some preparation. In order to build such a system, it is fundamental to install sensors offshore, near enough to the hypocenter at the landward side of the Pacific Trench Axis, in order to provide as much warning time as possible for the telemetry system to transmit the information to shore ahead of the seismic disturbance.

There are a number of different techniques and systems that have been employed or proposed to transmit data from seafloor (or downhole) sensors back to shore [6]. The techniques employed for getting the data back to land have been broadly characterized as “Wired to Shore”; “Wired to Surface” and “Wireless” as depicted in Table 1.

| | Real-time | Power Supply | Logistical | Cost |
|---|---|---|---|---|
| Wire to Shore | Excellent | Excellent | Difficult | Very High |
| Wire to Surface | Good | Good | Good | High |
| Wireless | Poor | Poor | Excellent | Low |

Table 1. Characteristics of Offshore Online Observatories

As evidenced by Table 1, there are numerous advantages afforded by an installation that is directly linked to shore by cable or “Wired to Shore” systems. These installations can provide seafloor or downhole sensors with nearly limitless power and bandwidth for data transmission, and most importantly when attempting a warning system for earthquakes or tsunamis, they afford continuous access to real-time data. As indicated, for installations that are far offshore, these can also be the most expensive and logistically difficult systems to install.

The cost to procure and install submarine cable for sensors placed far offshore becomes very expensive. Furthermore, other obstacles can make it difficult or impossible to land a cable onshore in some areas dependent upon environmental concerns, land usage and legal considerations. In these instances, an attractive alternative may be a “Wired to Surface” observatory. Data is transmitted from the seafloor to a surface buoy in real-time via a fiber optic link. While the data throughput back to shore is not as broadband as would be permitted by a fiber optic cable, advances in buoy-based satellite telemetry system now facilitate transmission up to 2-Mbps, delayed only by the round trip satellite delay. And while perhaps not as limitless as the shore-based power provided by a “Wired to Shore” observatory, diesel-powered electrical generators that can be routinely serviced aboard a surface buoy can supply an adequate and reliable source of electrical power for long-term monitoring. Harris Corporation has designed and built such a buoy based observatory called the Ocean Net system.

Figure 5 is a diagram showing the major components of a deployed Ocean Net system.

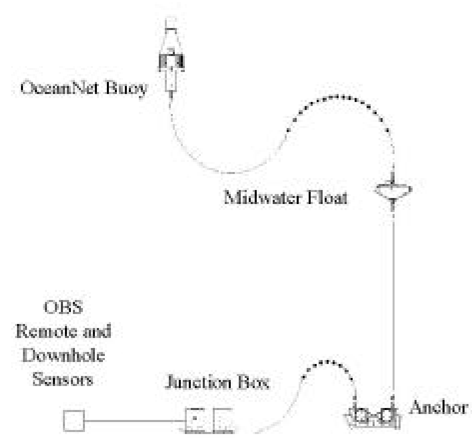


Fig. 5. Major Component of Ocean Net System

The Ocean Net system is designed to operate unmanned for up to six months between maintenance visits. The buoy carries onboard nearly 20,000 liters of diesel fuel. The diesel fuel is a stored in three flexible bladders. These bladders are contained within a free-flooding cylindrical Fuel Enclosure. The 3-m diameter Fuel Enclosure sits beneath the waterline, at the base of the 5-m buoy hull. At the base of the Fuel Enclosure is a 10-ton lead ballast weight. The resulting configuration aids in stabilization of the Ocean Net buoy. As the fuel from the flexible bladders is consumed, seawater replaces the volume it had occupied within the Fuel Enclosure, thereby limiting the "light ship" condition and altered dynamics of the hull. Figure 6 is a photograph of one of these Ocean Net buoys being deployed from a specially-configured Launch/Recovery Transport (LRT) barge.

Fig. 6. Ocean Net Buoy Being Deployed

While perhaps not as costly as deploying the hundreds of kilometers of submarine cable and landing it onshore as might be required for a "Wired to Shore" observatory, neither is deployment of the 50-ton Ocean Net buoy and its attendant subsea components a trivial task. A plan view of the LRT barge used in two previous Ocean Net deployments is provided in Figure 7. It is also possible to deploy the entire system employing suitably equipped vessels of opportunity contracted from the deployment vicinity.

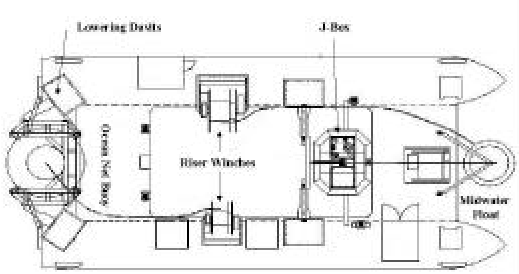


Fig. 7. Launch/Recovery/Transport (LRT) Barge

During the installation, the first component to be deployed is the Seafloor Junction Box. It is designed to serve as the hub for an array of other sensors. The Junction Box is equipped with ROV-wet-mateable connectors, facilitating the future expansion of additional sensor packages. These connectors provide both copper and optical fiber paths for data as well as power (up to 1-kW). It is deployed on the bottom approximately 1,500-m from the Anchor in order to reduce the risk of entanglement with the buoy riser cable during ROV intervention with the Junction Box. The ROV wet mate connectors are equipped with T-handles to facilitate intervention with ROV manipulators. Figure 8 is a photograph of the Seafloor Junction Box onboard ship prior to its deployment.


Fig. 8. Seafloor Junction Box

The two remaining elements of the major subsea components are the Anchor and Midwater Float. The anchor is somewhat unique in design. It provides its primary function of securing the mooring riser to the seafloor both through its 25-ton weight and embedment flukes. The lower riser is armored with several layers of aramid fiber and thus any external clamping forces to which it is subjected must be distributed over a suitable length of cable. In deference to this consideration, in order to take the strain off the mooring riser prior to transitioning along the bottom to the Seafloor Junction box, the anchor was outfitted with a pair (left hand helical and right hand helical) of Lebus ™ grooved drums. By "figure eighting" the riser around this pair of drums, the mooring tension is adequately reduced without the necessity of an additional pair of connectors and mechanical terminations in the lower riser. The flexibility afforded by this feature allows sections of cables to be made-up in advance prior to knowing the exact depth of the deployment site. The photograph in Figure 9 both shows the configuration of the counter-helical drums and provides some reference as to the size of the Anchor.


Fig. 9. Ocean Net Anchor System

Finally, the Midwater Float also serves a number of functions. First, it provides a transition point between the lower, aramid-armored riser cable and the upper, steel armored cable. At this transition, the Midwater Float supports wet-mateable connectors as well as a mechanical "weak link". The weak link and connectors are designed to allow the upper and lower riser cables to gracefully part should the mooring be snagged or subjected to forces greater than its design loads. This design is intended to permit reattachment by an ROV of the upper riser at the Midwater Float should they be pulled apart. Thus, any such mishap at the surface should not affect the seafloor installation. Figure 10 is a photograph of the Midwater Float rigged for deployment form the LRT barge.


Fig. 10. Midwater Float Onboard LRT Barge

The Ocean Net satellite communication system that enables it to send to shore in real-time, high bandwidth (up to 2-Mbps) transmissions of data from the open ocean is described in more detail elsewhere [7]. The system utilizes three separate satellite systems: INTELSAT, INMARSAT-C and Service ARGOS. The primary link that enables the continuous high data throughput from the various sensor packages is the C-Band INTELSAT system. An inertially-stabilized pedestal that is in constant motion to aim its 1.5-m dish antenna at a satellite in geosynchronous orbit some 35,000-km in space. The dynamic response of this pedestal is designed to maintain its pointing accuracy in conditions up to seastate six. In addition to this primary C-Band data link, there are a total of six L-Band (INMARSAT-C) antennae and a Service ARGOS PTT to transmit buoy location and a few select parameters.

Figure 11 depicts the various satellite communication systems that are involved in telemetering the data as well as providing command and control.

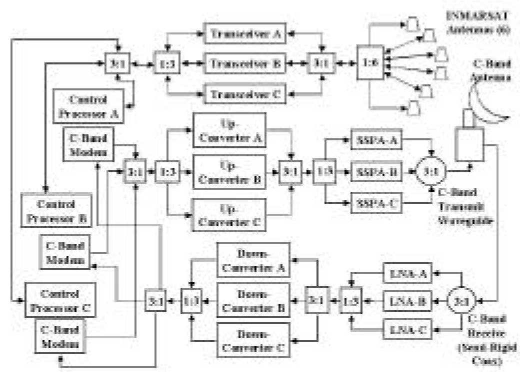


Fig. 11. Satellite Communication Systems

## 4. FUTURE OF OCEAN NET AND BOREHOLE AS AN EARTHQUAKE MONITORING/ WARNING SYSTEM FOR JAPAN

While the cost to build, deploy and operate a long term, buoy-based ocean observing system is not insignificant, the cost to run cables to shore, both to power and to retrieve data from mid-ocean sites may run many times more. As a real-time warning system, the additional delay instituted by the 70,000-km (roundtrip) satellite hop and terrestrial backhaul through the Public Switched Telephone Network (PSTN) place this system at something of a disadvantage as compared to a direct, hardwired system. The reporting time from the occurrence of the event to when it reaches controls on shore is critical. Further, the criticality of the application warrants consideration of some means of redundancy to the riser cable. This potential single-point failure component is subjected to severe environmental conditions.

The time (and therefor costs) required to complete these boreholes continues to decrease and new advances such as bonding techniques for securing precise data by sensors in the borehole continue to improve.

## 5. CONCLUSION

A real-time offshore borehole observation network in Japan will require a variety of different technologies to be applied. It is possible that Wired to Shore, Wired to Surface and Wireless observatories may all represent solutions to different portions of this problem. Observatories hardwired to shore represent a robust solution particularly where hypothetical focal regions are not too distant from shore. Wired to Surface observatories like the Ocean Net system provide both an attractive alternative for distant offshore sites as well as a means for transmitting continuous, near real-time data from downhole sensors that are not a part of an early detection system. Offline or non-real-time systems such as those that employ “pop up” messenger data pods represent a good complement in otherwise un-instrumented areas or as interim systems.

Construction of a real-time offshore borehole observation network off Japan may be made possible through application of the appropriate combination of these different offshore observation systems. A network such as that described could have the potential to serve as a disaster warning system for both earthquakes and subsequent tsunamis. These sensors and telemetry systems could be incorporated into a tsunami alarm system, permitting tsunami arrival time, tsunami height and affected area to be calculated and transmitted in sufficient time so as to help mitigate its disastrous impact. Such a system would benefit for not only Japan but also the surrounding Pacific Ocean countries.

## 6. ACKNOWLEDGEMENTS

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